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Avoided land use conversions and carbon loss from conservation purchases in California

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Abstract

Conversion of natural lands to residential and agricultural uses can limit carbon (C) storage. Conservation measures, such as purchasing land to prevent development, can preserve stored aboveground C. However, since it is difficult to know what would happen to the land in the absence of conservation interventions, the additional carbon benefit of these programs remains unknown. Therefore, we analyzed 73 coastal parcels (292,184 total acres) acquired by the California State Coastal Conservancy (SCC) and developed counterfactual scenarios to highlight the impact of conservation actions. We found that an additional 55 * 10^3 Mg aboveground C (1.357% of the total stored carbon) was protected. The methodology we develop here, which incorporates expert opinion and neighboring land conversion trends, effectively evaluates the impact of conservation purchases to prevent land conversion, and could be used to measure changes of various ecosystem services.

KEYWORDS: Land cover change; land use; landscape conservation; counterfactual analysis; highest and best use (HBU) of land

Introduction

As the human population continues to grow, and consumption patterns change, more land is needed to meet an increasing demand for food and housing (He, Zhang, Hunag, & Zhao, 2016; Nelson et al., 2010; Radeloff, Hammer, & Stewart, 2005; Wilson, Sleeter, & Davis, 2015). Land use decisions, whether they refer to changing existing land management practices, or converting natural landscapes for human use, can fundamentally change ecosystem health, balance, and species composition (Foley et al., 2005; Turner et al., 2007; Ellis et al., 2013). This impacts the future resource base, the global climate, and the natural capital of many regions (Ellis et al., 2013; Foley et al., 2005; Houghton & Goodale, 2004; Lambin, Geist, & Lepers, 2003; Lambin & Meyfroidt, 2011; Sleeter, Wilson, Soulard, & Liu, 2011). Urban development and agricultural expansion are two of the leading causes of land cover change (Cameron, Marty, & Holland, 2014; Radeloff, Hammer, & Stewart, 2005; Swenson & Franklin, 2000) resulting in habitat loss and fragmentation (Fischer & Lindenmayer, 2007; Swenson & Franklin, 2000), environmental degradation (Butsic, Gaeta, &

Radeloff, 2012), and loss in ecosystem services (Butsic et al., 2017; Eigenbrod et al., 2011; Guo & Gifford, 2002; He et al., 2016; Nelson et al., 2010).

Influenced by a suite of socio-economic, geologic, and biophysical processes, dynamic coastal environments are among the most vulnerable regions to rapid land use land cover changes (LULCC) (Riordan & Rundel, 2014; Rounsevell et al., 2012; Risk and Resilience in Coastal Regions, 2013; Wilson & Fischetti, 2010). In the United States, the rate of change recorded for coastal land cover is twice that of the rest of the country (NOAA – Office for Coastal Management, 2017). In California, increased residential development and agricultural expansion have contributed to significant land cover changes in coastal areas (Hale et al., 2009; Merenlender, 2000; Potter, 2013; Sleeter et al., 2011; Wilson et al., 2015). Land cover changes that convert natural vegetation to either developed or agricultural uses not only dramatically change the landscape, ecology, and scenery of the coastal region (Merenlender, 2000; Newburn, Reed, Berck, & Merenlender, 2006), but also impact the regional carbon budget by altering the carbon storage capacity of coastal ecosystems (Houghton & Nassikas, 2017; Pielke et al., 2002).

Since regional carbon (C) storage is closely related to the productivity and climate regulation capacity of terrestrial ecosystems, land cover changes affect the carbon storage capacity of natural lands, while influencing the balance between carbon sources and sinks, changing the carbon storage capacity of natural lands, and contributing to increased atmospheric C emissions (Brown et al., 2014; Eigenbrod et al., 2011; He et al., 2016; Houghton et al., 2012; Liu et al., 2009). Even though estimates of the net annual emissions of carbon from LULCC vary due to the different methodologies used to calculate emissions, and due to the difficulties of separating direct causes from natural and indirect effects (Houghton et al., 2012), it is widely recognized that changes in land cover will influence the trajectory of atmospheric CO2, and will impact the rate of global climate change in the coming century (Houghton et al., 2012; Mahmood, Pielke, Hubbard, Niyogi, & Bonan, 2010; Nelson et al., 2010).

California is one of the few jurisdictions in the United States to enact mandatory greenhouse gas emissions reductions, with pioneering efforts aimed at conversion to clean energy and ambitious carbon emission reduction goals (Gonzalez, Battles, Collins, Robards, & Saah, 2015). In 2006, the Global Warming Solutions Act (Assembly Bill, 32), marked the beginning of an integrated climate change program, creating a comprehensive multi-year plan to reduce and limit greenhouse gas (GHG) emissions (ARB, 2017). Assembly Bill 32 (AB 32) set California’s first GHG target which mandated the reduction of emissions to 1990 levels by 2020 (ARB, 2017). Adhering to the Paris Agreement goals, Executive Orders B-30–15 and SB 32 extended the goals of AB 32, and called for the doubling of the emission reduction rate, aiming for additional 40% reductions from 2020 to 2030 (ARB, 2017). The state’s aggressive emission reduction goals have sparked interest in assessing the carbon storage capacity of terrestrial ecosystems, and quantifying the impact that land use decisions have on the regional carbon cycle. Since California’s coast redwood forest (*Sequoia sempervirens*) represent ecosystems with high carbon densities (Gonzalez et al., 2015), conservation and strategic management of these lands can potentially play a critical role in climate mitigation efforts at regional, and even global scales.

Understanding the effectiveness of conservation programs remains a challenge however, because conserved lands are not random in nature, making regression analysis oftentimes inappropriate. To get around this issue, counterfactual analysis creates a non-observable case and compares it to an actual case to determine the effect on an intervention (Caplow, Jagger, Lawlor, & Sills, 2011; Ferraro & Pattanayak, 2006; He et al., 2013). This method is often used when assessing the effectiveness of protected areas, and in the process of analyzing the outcome of land use policy changes (Ferraro & Pattanayak, 2006; He et al., 2013; Jones & Lewis, 2015). Different techniques exist for developing counterfactual scenarios, including matching (Andam, Ferraro, Pfaff, Sanchez-Azofeifa, & Robalino, 2008), statistical modeling (Jones & Lewis, 2015; Mondal & Southworth, 2010), and scenario building (He et al., 2013).

Established in 1976, the California State Coastal Conservancy (SCC) was created by the California State Legislature to promote open space conservation across California’s coastal lands. The goals of the SCC directly stem from the California Coastal Act of 1976. The legislation stipulates the importance of protecting the coastal zone from deterioration and destruction, and the importance of maintaining its ecological balance, and scenic properties. Throughout the language of the Act, Section 30,001, the coastal environment is designated as a distinct and valuable natural resource with a delicately balanced ecosystem Public Resource Code, Division 20, California Coastal Act, (2018) With the goal of protecting, preserving, and restoring the coastal resources of the State, the SCC has purchased more than 400 properties of wildlife habitat, recreational lands, farmland, and scenic open space (State of California Coastal Conservancy, 2017). Therefore, focusing on a subset of some of the largest SCC acquisitions, we addressed the following questions:

- 1. How much land conversion was avoided by SCC purchases?
- 2. What were the main vegetation types prevented from converting to other uses?
- 3. How much aboveground C loss was avoided by SCC purchases?

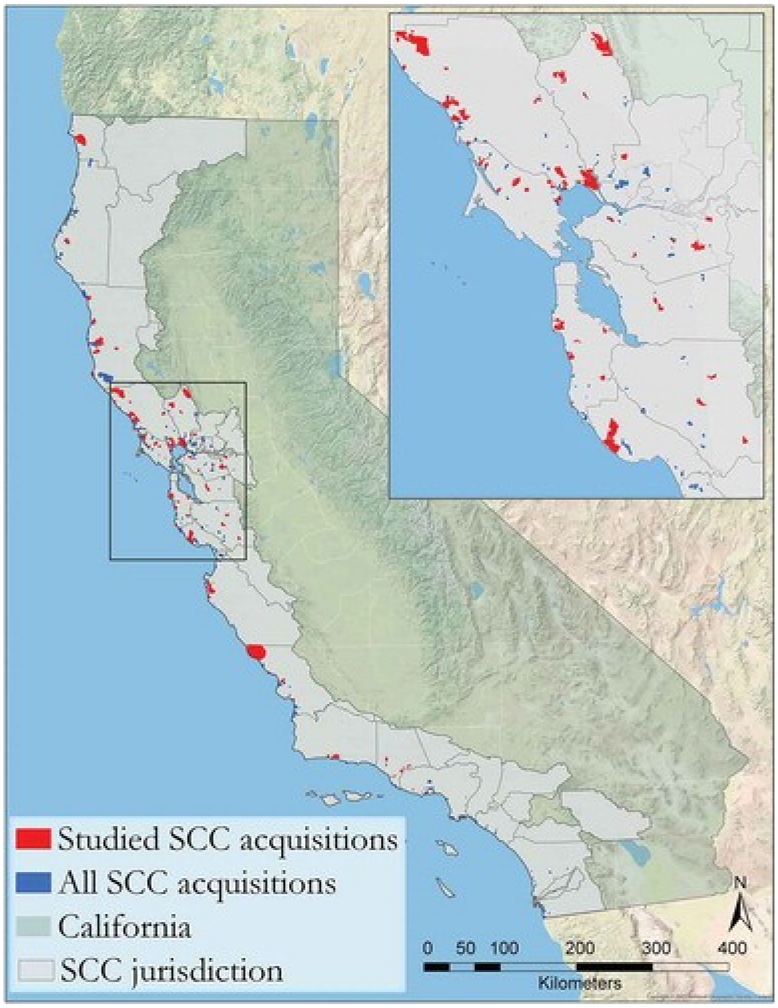
To address these questions, we analyzed 73 coastal parcels (the largest properties by acreage, and the ones that had sufficient appraisal information available) purchased by the SCC. We designed a novel approach to building counterfactual land use scenarios by incorporating detailed appraisal reports solicited by the SCC, documents that stipulated the highest and best use of the land in the absence of conservation actions. We believe that including this information in the design of the counterfactual landscape provides a compelling perspective on the highest valued alternative use of the land, given exiting market demands and developmental pressures at the time when the properties were purchased for conservation purposes. By estimating the amount, and type of vegetation that was prevented from conversion as a result of conservation purchases, the results of our analysis provide insight on the elements that shape the relationship between local land use decisions and the regional carbon budget. We chose to develop a new method rather than using an existing methods such as difference-in-differences models (Puhani, 2012) for two main reasons. First, for many of the properties, historical parcel data for the surrounding area does not exists. Many municipalities do not have digital parcel layers from the date when the SCC properties where purchased, making the use of econometric models difficult. More importantly, many of the SSC parcels are exceptional for their size and natural state. Therefore, it would be difficult to find valid ‘control’ parcels with which to compare the SSC parcels in an econometric framework. Given these difficulties, we believe the HBU from the appraisal reports represents the most accurate method to calculate avoided conversions.

Materials and methods

Study area

Throughout California, across 22 coastal counties, the SCC has conserved over 370,000 acres by purchasing lands threatened by development through fee titles and easements (Figure 1). These lands encompass an array of properties, varying in size, and characterized by a mosaic of topographies and vegetation types – including grasslands, wetlands, dunes, coastal sage, chaparral, oak woodlands, deciduous and evergreen forests, and coast redwood forests (State of California Coastal Conservancy, 2017).

Figure 1. Map of California State Coastal Conservancy (SCC) jurisdiction and land acquisitions. Insert represents the properties clustered around the Bay Area.



Data

To model land cover, we used geospatial data from the Landscape Fire and Resource Management Planning Tools (LandFire) (Ryan & Opperman, 2013). The LandFire program is an interagency collaboration between the U.S. Department of Agriculture Forest Service and U.S. Department of the Interior initiated in response to the threat of mega-fires, and designed to provide consistent landscape scale data to help cross-boundary planning and land management (LandFire, n.d.). The LandFire database provides a comprehensive set of quantitative vegetation models and nationwide digital spatial data layers (30 m resolution) on vegetation cover, fire, disturbance regimes, and fuel loads (Ryan & Opperman, 2013). To effectively document land cover changes through time, we focused on differences in vegetation cover between the years 2001 and 2010. Among the properties studied, 39 were purchased during this time period (see Table A1 in Appendix). We chose this specific time frame because the aboveground C data (used to estimate the amount of avoided C emissions) was calculated by Gonzalez et al. (2015) for the time period 2001–2010.

Second, to quantify the aboveground C storage capacity of different vegetation types we used 1,083 biomass classes created from the LandFire data layers through the work of Gonzalez et al. (2015). The biomass classes represented a classification of vegetation cover that reflected the estimated amount of carbon stored in its biomass. Specifically, Gonzalez et al. (2015) used a classification of vegetation type, height, and cover, combined with calibrated measures of carbon density for each class to assign carbon biomass values to vegetation pixels. The algorithms used estimated the vegetation height and fractional cover for each pixel using a series of field observations and inventory plots, along with reflectance from several Landsat spectral bands (Gonzalez et al., 2015). Since changes in land cover and vegetation height were reflected in the Landsat imagery, the resulting vegetation classification algorithm grouped existing vegetation in classes based on ranges of height (i.e. for the grassland vegetation class the distinction was made between herbs 0–0.5 m, 0.5–1.0 m, and > 1 m), as well as cover.

Differences in vegetation type, height, and cover influence the amount of stored aboveground C in a particular vegetation type, therefore, vegetation types were grouped based on these characteristics. For example, the grassland vegetation class was separated into three distinct classes: 1) grassland class characterized by herb cover less than 20%, 2) grassland class with herb cover between 20% and 40%, and 3) grassland class characterized by herb cover between 40% and 100%. Other vegetation classes (such as coast redwoods) had similar sub-class distinctions based on their height and cover, however not all of them were grouped into separate classes. For instance, unlike the grassland vegetation class, the mesic chaparral vegetation class was not further split into different vegetation classes, rather, it encompassed all shrubs taller than 3 m (see Table A2 in Appendix). The distinction between vegetation types based on the type, height, and percent cover was done solely for natural vegetation cover (excluding agricultural and urban areas). Gonzalez et al. (2015) assumed that land cover types such as: agriculture (including vineyards), urban development, infrastructure, and roads, had zero aboveground C storage potential. We used this biomass data to calculate the amount of avoided vegetation conversion, and the amount of avoided C emissions.

Third, to define the geographic extent of the area studied, we used spatial data provided by the SCC. The data included a dataset containing the spatial boundaries of 407 land parcels purchased by the Conservancy. The properties were purchased between 1978 and 2017, and varied in size from less than 1/10 of an acre to 80,733 acres (the largest acquisition being Hearst Ranch). We analyzed a subset of 73 properties, some of the largest acquisitions for which sufficient property appraisal data was available (Figure 1). These properties are a representative group among the SCC acquisitions in terms of their topographic and land cover characteristics, having similar dominant vegetation classes as the ones found on the other SCC acquisitions not studied (Table 1). According to the HBU section of the appraisal reports, among the 73 acquisitions studied, 57 properties would have experienced some amount of conversion had they not been purchased by the SCC for conservation purposes. We developed our counterfactual scenario simulation based on these 57 properties and assumed that no land conversion would occur on the other 16 acquisitions. Among the 57 properties, the mean property size was 4,175 acres, and the median size was 1,293 acres. These lands were purchased between 1991 and 2016 (Table A1 in Appendix). In total, our analysis included approximately 292,184 acres of the 381,156 acres (across all SCC acquisitions), approximately 76.7% of the total land owned by the SCC.

Table 1. Summary statistics for the 73 properties studied (including the 57 properties that converted to development and/or vineyards and 16 properties that did not convert under the HBU scenario).

Summary Statistics	Properties in sample	Other SCC acquisitions (not studied)
Total Acres	292,184	88,927
Average parcel size	4,002	265
Max parcel size	80,734	23,773
Min parcel size	518	0.08
Median parcel size	1,292	102
Min acres converted to dev	2	N/A
Max acres converted to dev	1,277	N/A
Min acres converted to vineyard	190	N/A
Max acres converted to vineyard	3,500	N/A
Mean acres converted to development	120	N/A
Mean acres converted to vineyards	123	N/A
Top 4 vegetation classes found across properties	1. Coastal Redwoods 2. Grassland 3. Central and Southern Mixed Evergreen Woodland 4. Mesic Chaparral	1. Coastal Redwoods 2. Grassland 3. Mesic Chaparral 4. Mixed Evergreen Forest

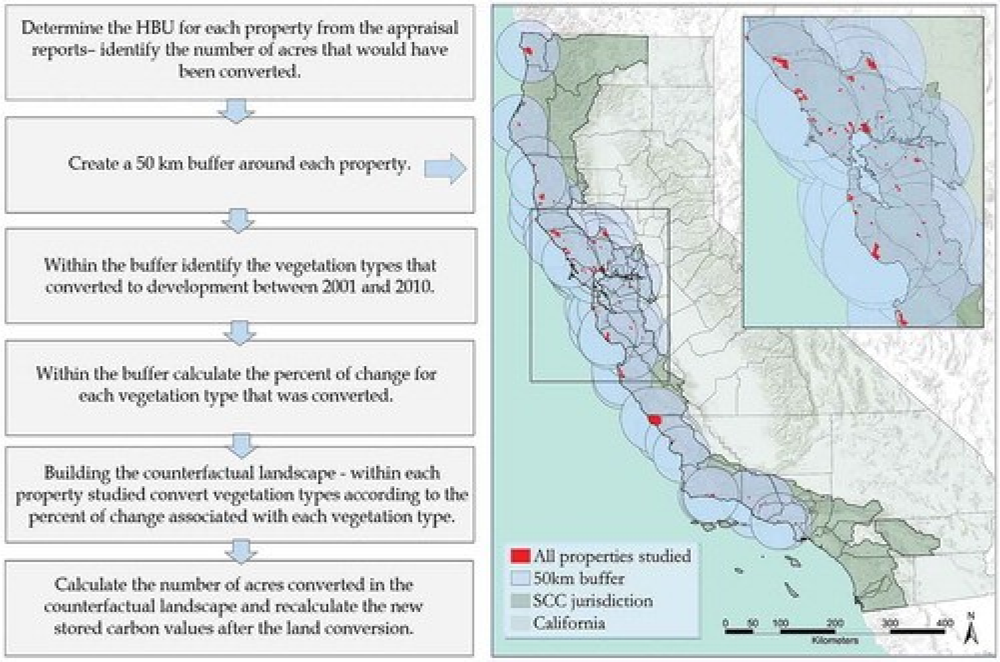
Property appraisal data was also provided by the SCC in the form of electronic and printed appraisal reports (full length documents describing the property, and providing a detailed analysis of its market value before and after the conservation easement). The property appraisal dataset also contained appraisal summaries (short documents highlighting the main points of the appraisal report, addressing the highest and best use of the land, the value of the land, zoning, etc.), and appraisal reviews (documents that concisely describe the findings of the appraisal report, mostly focusing on the estimated value of the land). The information found in these documents was essential in calculating the amount of development that would have taken place on each property had the SCC not purchased the land for conservation purposes. The appraisal reports did not indicate what type of vegetation would have been converted to other uses, rather these documents provided an indication on the market demand for housing and agricultural development, and assessed the likelihood that the subject property would be subdivided to meet these demands. By highlighting not only the allowable development on each of the SCC acquisitions, but also determining the possibility that a property would be converted to other uses, the appraisal reports provided a valuable foundation for our counterfactual scenario. Some of the SCC acquisitions only had a summary appraiser review, a brief document which did not have sufficient information on the development potential of the land, and therefore, those properties were not included in the study.

Counterfactual scenario development

To evaluate the potential changes in land cover in the absence of conservation interventions, we generated counterfactual outcomes to capture possible conversions that would result from the *Highest and Best Use (HBU)* of the land as stipulated in the property appraisal report. This section of the appraisal report highlighted what would have happened to the land in the absence of an intervention. The appraiser reports were conducted in accordance to established land valuation standards and regulations. For example, the appraisal conducted for Preservation Ranch (one of the properties studied) was prepared in accordance with the current Uniform Appraisal standards for Federal Land Acquisitions (UASFLA), the Standards of Professional Practice and the Code of Ethics of the Appraisal Institute, the Uniform Standards of Professional appraisal Practice (USPAP), The Coastal Conservancy Environmental Appraisal Specifications, the California Department of General Services appraisal Specifications, and the appraisal specifications provided by Senate Bill No. 1266 (Forsburg, 2012). We chose to rely on this information to build our counterfactual landscape since it provided a reliable estimate of the most valued alternative use of the property had the SCC not purchased it.

The counterfactual approach that we used to quantify the avoided vegetation conversions differs from existing methodologies since it relies on a combination of information provided by the property appraisal reports (HBU section of the report), combined with an assessment of land conversion trends within the surrounding areas (Figure 2). This assessment of neighboring areas highlights which vegetation types were converted to development or agriculture during the time period studied. Other neighboring SCC acquisitions were excluded from the buffer area. Finally, we used existing land cover data estimating the aboveground C (provided by Gonzalez et al., 2015), along with data generated by the counterfactual simulation to estimate the amount of avoided C emissions resulted from conservation actions.

Figure 2. Schematic representation of the general steps used in the design of the counterfactual scenario (left). Buffers around each SCC acquisition (right).



I. Determining the amount of development on each property

The HBU section of the appraisal report was prepared by a California certified general appraiser, a professional familiar with the property, and with the local land market. The appraisal methodology assessed the value of the property using a number of different methodologies such as: the component valuation approach, the sales comparison approach (analysis of comparable property sales with adjustment for differences between the subject and comparables), the income approach, and the cost approach (Strupp, 2007). Each component of the evaluation methodology analyzes different aspects of the property (Forsburg, 2012).

The HBU section of the appraisal report determined the use of the property that would maximize the economic rents, given its location, and taking into account physical (topographical) and zoning constraints, supply and demand forces, and real estate market trends, among other things. The HBU is defined as the '*The reasonable probable and legal use of vacant land or an improved property that is legally permissible, physically possible, appropriately supported, financially feasible, and results in the highest value*' (The Appraisal Institute, 2013).

The conclusions of the HBU portion of the appraisal report varied among properties based on case-specific characteristics. The size and shape of the property, the zoning (the maximum allowed rural development density), the location, and the topographic characteristics of the land (elevation, slope, steepness of the terrain) were all important determinants evaluated by the appraiser writing the report (see Table A1 in Appendix). The ease of access to essential utilities (such as roads, water, sewer, and electricity), historical use, and proximity to nearby urban centers were also considered throughout the assessment. Under the HBU scenario, a number of properties would have been partially or completely converted to residential development, others would have been used for both rural development and vineyard production, some would have been used for timber production, and the rest would have remained as open land for recreation, grazing and wildlife conservation. We considered the HBU section of the appraisal report to be an accurate representation of what would have happened to the land had it not been purchased by the SCC for public resource protection.

Among the 73 studied properties, the appraisal report for 16 properties concluded that the HBU of the land would be attained if the land remained undeveloped – as open space. This conclusion was based either on the steepness of the terrain, or remote location with problematic access to basic utilities such as power, water, and sewage. In making this designation, the appraiser also took into account development costs and difficulty, and historical use. Properties that historically were flood control areas, wetland restoration projects, open recreational space used for hunting and fishing, or areas home to endangered wildlife species, and essential wildlife corridors, were considered to reach their highest and best use if they were to be left undeveloped as permanent open space. According to the property appraisal report, the remaining 57 properties would have had some degree of land conversion under the HBU scenario had they not been purchased for conservation purposes (Appendix Table A1). We created counterfactual scenarios for these 57 properties, assuming that the land cover would have not changed in the other 16 properties, regardless of their ownership.

II. Estimation strategy

First, the zoning designation relevant to each property was a key determinant dictating the amount and density of the potential development. Zoning regulations typically restrict the type and intensity of land use (i.e. housing density) that can occur (Theobald, 2003). Second, properties having certificates of compliance (COC) also determined the amount of development permissible. A certificate of compliance is a document which, once approved and recorded, indicates that an area is an existing legal lot or parcel which may be sold, leased, or financed separately from other pieces of property without further processing required under the Subdivision Map Act (Subdivisions Article 1. 9–6.106). The number of COCs associated with each property (if any) established the number of lots in which the property can be subdivided. Third, the number of potential administrative certificate of compliance (subdivision) parcels (ACC) was also important information found in the appraisal document, since it provided a description of the amount of potential development that could take place on each of the properties. ACC parcels are separate legal parcels recognized by the county that predate the existing Assessor’s parcels (County of Sonoma, 2018).

In many cases, appraisal reports often used the number of COCs or ACCs to refer to potential development, rather than using the number of developable acres. To convert from the number of COCs or ACCs to land area, we assumed that each COC and ACC encompassed roughly 2 acres. Even though in most cases less than 2 acres would have been converted into completely impermeable surfaces, we selected 2 acres to represent the size of a rural development unit since we believe that this would be large enough to encompass the development footprint of the rural home along with the yard, walkways, barns, and other potential outbuildings associated with the developed property. Within this area, low carbon land cover such as yards would likely dominate sites around rural development. The validity and implications of assigning a 2 acre footprint to a unit of development were further tested by running a sensitivity analysis.

III. Developing a counterfactual landscape

We used ArcMap 10.4.1 (ESRI 2016. ArcGIS Desktop: Release 10.4 Redlands, CA: Environmental Systems Research Institute) and Python 2.7.10 (arcPy) to construct an alternative land cover scenario for each property. The land cover (vegetation data) used in developing the counterfactual landscape was in the form of raster layers with a cell size of 30 m^2. Therefore, once we identified the total acres that would have been developed under the HBU scenario for each property, we converted this number into square meters, and calculated the number of 30 m^2 pixels of vegetation conversion associated with each property. Specifically, each pixel represented a 30 × 30 m area, the smallest mapping unit of our analysis.

Taking into account the amount of conversion stipulated by the HBU and considering land cover changes likely to occur in the area, we assumed that conversions on each property would follow similar trends to nearby conversions (Landis & Zhang, 1998; Towe, Nickerson, & Bockstael, 2008). To document nearby conversions, we created a 50 km buffer around each of the 57 studied properties, and identified the vegetation types that were converted to development from 2001 to 2010 within the buffer area. We calculated this by overlaying the 2010 land cover raster and the 2001 raster, and documenting which pixels were classified as vegetation in 2001, yet classified as development in 2010. We further looked at the percent of change associated with each vegetation type by dividing the acres converted of a particular vegetation type by the total number of acres converted within the buffer. The result was the amount of land cover change within the buffer area expressed as a table displaying the vegetation classes present, and their associated percent of change. Vegetation classes that did not convert to development during the time period studied had an associated zero percent of change.

Identifying the land conversion trends within the buffer areas revealed which vegetation types were more likely to be converted to other land uses when market forces dictate land allocation decisions. A similar algorithm was applied to identify vegetation types converted to vineyards within the buffer during the period studied. Next, we documented which vegetation types in the buffer area were also found within the properties (Table 2). For 25 of the studied properties, not all the vegetation types from the buffer were found on the SCC acquisitions, therefore, we calculated the relative percentages associated with each vegetation type. This was done by summing up the total percentages of the vegetation classes found within the property, and dividing the amount of change associated with each vegetation class by this new total. The relative percentages provided accurate information on how much of each vegetation type was converted in the buffer with respect to other vegetation types within the SCC acquisitions. .

Table 2. Percent of different vegetation classes found in: the 50 km buffer, in the studied properties, in the remaining SCC acquisitions not included in the study, and in the 25 km buffer.

Vegetation type (veg)	% veg in 50 buffer	% veg in sampled properties	% veg in properties not studied	% veg in 25 km buffer
Barren	0.81	0.07	2.85	0.38
Coastal Redwood Forest	11.70	23.94	33.88	18.86
Blue Oak-Foothill Pine Woodland and Savanna	6.17	2.15	0.88	5.84
Mesic Chaparral	8.71	8.22	11.93	10.80
Montane Jeffrey Pine(-Ponderosa Pine) Woodland	0.18	0.05	0.05	0.10
Montane Riparian Systems	1.35	1.83	1.19	1.57
Montane Woodland and Chaparral	1.39	2.25	2.90	1.71
Central and Southern Mixed Evergreen Woodland	9.34	19.25	4.05	11.03
Deciduous open tree canopy	1.10	0.63	0.52	1.10
Deciduous sparse tree canopy	0.13	0.11	0.02	0.13
Evergreen closed tree canopy	0.33	0.48	0.09	0.25
Evergreen open tree canopy	0.75	0.72	0.43	0.81
Grassland	29.08	19.81	13.34	22.46
Great Basin Pinyon-Juniper Woodland	0.42	0.00	0.00	0.01
Herbaceous-shrub-steppe	0.75	1.17	2.32	1.28
Herbaceous Wet	0.56	0.45	3.33	0.93
Dry-Mesic Mixed Conifer Forest and Woodland	3.52	2.67	0.80	2.42
Black Oak-Conifer Forest and Woodland	0.63	0.56	0.30	0.80
Mesic Mixed Conifer Forest and Woodland	0.48	0.01	0.01	0.07
Mixed Evergreen Forest	2.55	0.55	9.64	1.99
Mixed Oak Woodland	1.36	0.12	0.25	1.06
Red Fir Forest	0.00	0.00	0.00	0.00
Sparsely Vegetated Systems	0.28	0.11	0.58	0.22
Subalpine Woodland	0.00	0.00	0.00	0.00
Mixed Evergreen-deciduous sparse tree canopy	0.47	0.28	0.58	0.69
Mojave Mid-Elevation Mixed Desert Scrub	0.07	0.00	0.00	0.03
Warm Desert Sparsely Vegetated Systems	0.03	0.00	0.00	0.00
Northern and Central California Dry-Mesic Chaparral	4.53	2.46	1.67	4.66
Shrubland	0.18	0.12	0.22	0.19
Sonora-Mojave Salt Desert Scrub	0.01	0.00	0.00	0.00
Sonora-Mojave Semi-Desert Chaparral	1.03	0.00	0.03	0.08
Southern Coastal Scrub	5.29	3.99	4.89	4.79
Southern Dry-Mesic Chaparral	4.28	2.87	1.47	3.14
Southern Oak Woodland and Savanna	2.52	5.14	1.77	2.60

The prevalent land conversion trends were applied to each of the studied properties, considering both the amount of conversion stipulated by the HBU for each property, and the relative percent associated with each vegetation type found within the property. For example, if the HBU called for 300 acres of residential development, we looked at all conversions to residential development between 2001–2010 within 50 km of the property, and calculated the percent conversion from each vegetation type (i.e. 10% of all residential conversion was from deciduous forest, 50% from grasslands, and 40% from shrubland). We implemented the land conversion trends within the counterfactual scenario such that 10% of residential development called for by the HBU on the SCC acquisition would come from deciduous forest, 50% from grasslands, and 40% from shrubland. If, for example, deciduous forest was absent, or there was not enough to reach the desired 10%, the remaining portion of development was spread among the other vegetation types proportionately. The result of the algorithm created a dataset representing the change in vegetation cover within each studied property under the HBU scenario. A similar algorithm was used when determining the amount, and type of vegetation converted to vineyards within the buffer area.

We made several assumptions in developing this methodology. First, we assumed that the opinion of the appraiser recorded in the HBU section of the appraisal report represents an accurate evaluation of what would have happened to the property if land use decisions are guided by maximizing the economic potential of the land. The appraisal reports follow established land evaluation standards, and consider various factors that could affect the value of the property including legal, economic, political, and market conditions (The Tasa Group, 2018). Therefore, we consider these expert opinions to be accurate for the cases we examined.

Second, we estimated that each unit of residential development roughly resulted in 2 acres of vegetation conversion because specific acreage was not listed in the appraisal reports. Thus, if the approval for 10 COC subdivision parcels was granted on the property, then the total area assumed to be developed was 20 acres. Third, we assumed that the conversion trends found within the buffer surrounding the property would also apply within each of the SCC acquisitions.

Fourth, we assumed that once a property was purchased by the SCC, no development (either residential or agricultural) would occur on the property. We based this assumption on the following elements. One of the objectives of the SCC is to preserve wildlife habitat and scenic open space, and therefore, the state agency does not allow any large-scale land conversions to occur on its lands, and we are unaware of any cases where conversions have occurred after and SSC purchase. In addition to this, the appraisal reports clearly stipulated a value of the land in its current state (unencumbered by the conservation easement), as well as the value of the property after the conservation easement would be applied. The latter was always a substantially lower property value due to the land use restrictions imposed by the easement.

Lastly, we considered a 50 km buffer large enough to capture relevant local land conversion trends, yet small enough to be able to effectively highlight land conversion trends within the immediate vicinity of the subject property. The areas captured within this buffer largely encompass the regions under SCC jurisdiction, areas regulated by the California Coastal Act. Using a larger buffer than 50 km would include areas outside the SCC jurisdiction, and outside the coastal zone. Consequently, we did not consider using over a buffer larger than a 50 km radius.

Calculating the amount of carbon lost under the counterfactual scenario

After creating the counterfactual landscape, we used RStudio Version 0.99.489 to quantify the amount of C stored on each of the SCC parcels. We used the biomass data provided by Gonzalez et al. (2015) and analyzed the amount of C stored on the SCC acquisitions both prior, and following conversion. We calculated: the area converted for each parcel (highlighting how much of the original parcel was classified as either development or agriculture), as well as the carbon density for each property before and after conversion. The result of our analysis provided a detailed table with the following attributes: area that would have been converted under the counterfactual; percent of parcel that would have been converted; total aboveground carbon of the parcel; total aboveground carbon lost due to development under the counterfactual scenario; percent C lost; carbon density per ha prior to counterfactual; carbon density after counterfactual; and average C density of pixels that were converted under the counterfactual scenario. We further summarized the total aboveground C lost across all properties studied, and found the total amount of avoided C lost as a result of conservation purchases.

Sensitivity analysis

In the process of modelling land use decisions under a counterfactual scenario we made several assumptions. Each assumption is characterized by a range of limitations. For instance, in the case that the appraisal report underestimated the amount of development taken place on the land, the amount of conserved carbon would have also been underestimated. In addition to this, the estimated footprint of a developed housing unit (roughly equal to 2 acres) and the selected 50 km buffer size, introduced a certain degree of uncertainty in our counterfactual landscape model. These assumptions could have led to the overestimation, or underestimation of the amount of development prevented by conservation interventions. Therefore, to further test the robustness of our results, we conducted a sensitivity analysis to evaluate part of the uncertainty stemming from our assumptions. We calculated the amount of land conversion and carbon lost under two different extreme scenarios, as well as explored the possibility of using a smaller buffer area (25 km).

In the first scenario, we assumed that the appraisal report significantly underestimated the amount of development that would take place on the property under the HBU of the land, and therefore, we increased the total acreage converted by 50%. Consequently we developed a counterfactual landscape close to the upper limit of number of acres that could have potentially be converted. In the second scenario, we assumed that the report overestimated the number of acres converted, and thus, we reduced the acres converted by 50%, analyzing the lower limit of potential land cover changes on the landscape.

Studying the results of the counterfactual simulation under these two extreme scenarios also addressed the assumption that one unit of development takes place on 2 acres of land. If more than 2 acres would have been developed, then this underestimation would be addressed by the first scenario (50% more acres converted under the HBU). Similarly, in the case that the 2 acres associated with one unit of development is an overestimation, then the second scenario would account for this. Additionally, we also tested the choice of a 50 km buffer as an effective area to study land conversion trends surrounding the SCC acquisitions by creating a smaller, 25 km buffer area surrounding each acquisition.

Results

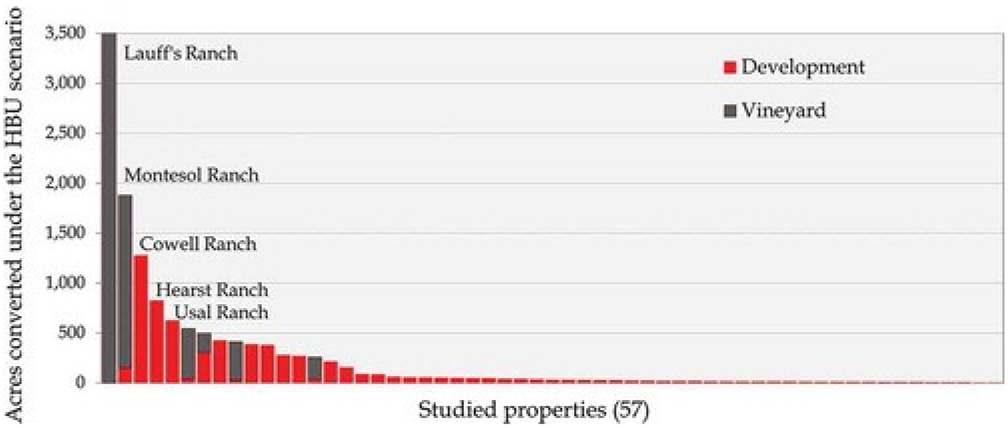
Amount of conversion

Among the 57 properties, 5 of them (North Point Ranch, Roche Ranch, Preservation Ranch, Montesol Ranch, and Wildlake Ranch) would have experienced conversion to both residential development and vineyard production. One property, Lauff's Ranch was the largest single property in terms of avoided conversions, with 3,500 acres of conversion prevented all solely from vineyard establishment (see Table A1 in Appendix).

The results of the counterfactual scenario show that 13,859 acres (5.82% of the total land across the 57 acquisitions) would have been transformed to other uses in the absence of conservation actions. The mean area that would have converted to development was 120 acres, the median was 29 acres, while the minimum number of acres converted under the counterfactual was 2 acres and the maximum was 1,277 (Table 1). In the case of conversion to vineyards, the mean acres that would have converted was 123 acres, the median was 0, (since only 6 properties would have experience conversion to vineyards), the minimum acres converted under the counterfactual was 0, while the maximum acres converted to vineyard was 3,500. (Table 1).

Based on the information provided in the appraisal reports, housing development was predicted to take place on 6,867 acres, and vineyard cultivation was predicted to take place on 6,992 acres (Figure 3). The other top properties that would have had the most conversion under the counterfactual scenario were: Hearst Ranch (80,734 total acres – 824 acres converted to development), Cowell Ranch (3,817 total acres – 1,277 acres converted to development), Usal Forest Shady Dell Creek Acquisition (3,629 total acres – 628 acres converted to development), and Preservation Ranch (19,634 total acres – 308 acres converted to development and 190 acres converted to vineyard). As a percent of their area, the properties with the largest avoided conversions were: Bahia Ranch (65.5% avoided), Gleason Ranch (41.9% avoided), Cowell Ranch (33.4% avoided), North Point Joint Venture (32.3% avoided) and Lauff's Ranch (28.5%).

Figure 3. Summary across the 57 properties in terms of housing development vs. vineyard conversion under the HBU of the land.



Vegetation types that would have been converted

The top vegetation types that would have been converted under the HBU scenario across all studied properties were: grassland cover between 40% and 100% (7,225 acres), mesic chaparral (1,471 acres), grassland cover between 20% and 40% (1,200 acres), northern and central dry-mesic chaparral (693 acres), montane woodland and chaparral (564 acres), and southern coastal shrub (372 acres). When calculating the vegetation lost as a percent of the total vegetation found within the 57 properties, the rankings change, with grassland cover between 20 % and 40% experiencing the most conversion (31.44%), followed by lower montane blue oak-foothill pine woodland and savanna (21.93%) (Table 3).

Table 3. Top vegetation classes that were lost under the counterfactual scenario as a percent of the total vegetation in the 57 studied properties.

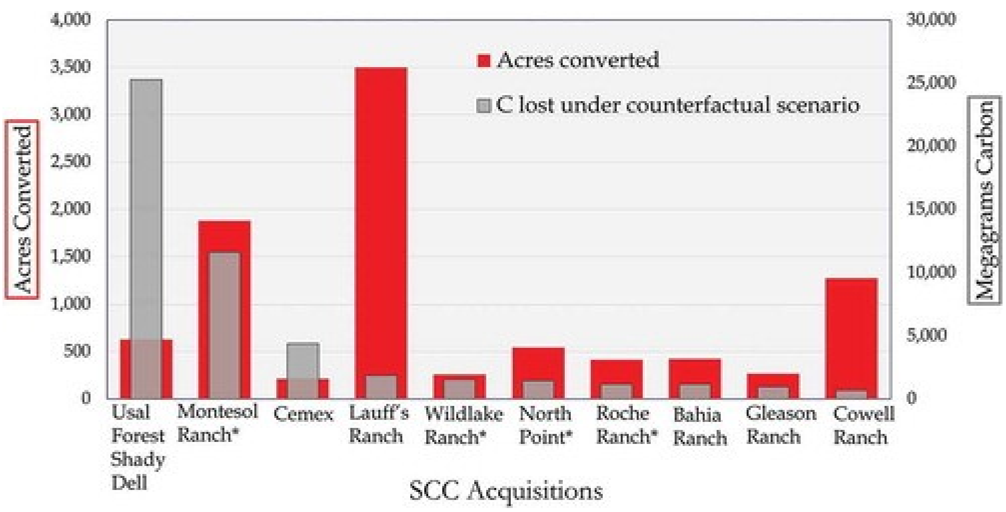
Vegetation Type	Percent that was lost under counterfactual
Grassland cover between 20% and 40%	31.44%
Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	21.93%
Grassland cover between 40% and 100%	18.65%
Northern and Central Dry-Mesic Chaparral	15.48%
Montane Woodland and Chaparral	11.70%
Mesic Chaparral	7.43%
Southern Coastal Scrub	3.05%
Herbaceous-shrub-steppe	2.03%
Coastal Redwoods	1.99%

Amount of carbon loss

Calculations completed using the biomass classes and associated carbon values from Gonzalez et al. (2015) suggested that all 407 SCC acquisitions (including properties that did not convert to other uses under the HBU scenario) store more than 7 million metric tons of aboveground C at the time of analysis (2010), with an average density of more than 50 Mg C/ha. This is more than 2.5 times higher than the average for California statewide, and reflects the importance of coast redwood forests in the SCC portfolio, which hold more than 50% of the total carbon stock (Ackerly et al., 2018).

Based on the estimated C values associated with the vegetation types found on the studied SCC acquisitions, the avoided land use conversion translated into approximately $55 * 10^3$ Mg (55,540 Mg) of avoided aboveground C loss (1.357% out of a total of the approximately $4 * 10^6$ Mg (4,090,650 Mg) total aboveground C stored across all 57 properties). The carbon lost from land use conversion depended both on the number of acres converted and on the type of vegetation converted. C loss ranged from 1 Mg(C) to a maximum of 25,300 Mg(C), with a mean of 990 Mg(C). The top ten properties that would have incurred the most aboveground C lost due to development are: Usal Forest Shady Dell Creek Acquisition, Montesol Ranch, Cemex Redwoods Acquisition, Lauff's Ranch, Wildlake Lake Acquisition, North Point Joint Venture Acquisition, Roche Ranch, Bahia Ranch, Gleason Ranch, and Cowell Ranch (Figure 4).

Figure 4. Properties that would have had the most aboveground C lost due to development under counterfactual scenario (grey) and associated total acres converted (red).*Properties that experience conversion to both development and vineyards under the HBU.



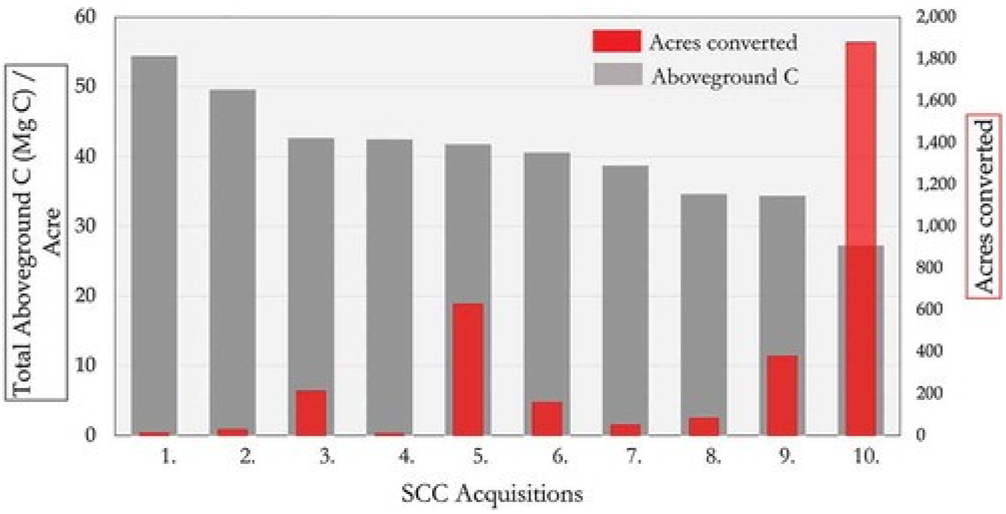
The vegetation cover on each property (Figure 5) was a critical factor determining the amount of carbon lost in the absence of conservation initiatives. For example, 63% of all avoided aboveground C loss came from two properties – Usal Forest Shady Dell (approximately $25 * 10^3$ Mg), and Montesol Ranch (approximately $12 * 10^3$ Mg) – which both had high development potential, and vegetation with extremely high C density (primarily coast redwood forests). Lauff's Ranch, which had the largest area of avoided conversion, had only the fourth most C loss avoided, despite contributing 2,872 acres of avoided conversion, because the converted vegetation would have been primarily chaparral and grasslands, vegetation types with a relatively low C density. Due to this underlying difference in vegetation carbon density across properties, Lauff's Ranch had only 7% of the avoided C loss of Usal Forest Shady Dell.

Figure 5. Top 10 SCC acquisitions ranked by the avoided C emissions: 1. Usal Forest Shady Dell Aquisition; 2. Montesol Ranch; 3. Cemex Redwoods; 4. Lauff's Ranch; 5. Wildlake Ranch; 6. North Point Ranch; 7. Roche Ranch; 8. Bahia Ranch; 10. Cowell Ranch. *Note: Inserts are at different scales.

To further explore the relationship between aboveground C stored per acre and number of acres converted under the HBU scenario, we ranked the top 10 properties that have the highest aboveground C per acre and associated total acres converted for each property (Figure 6). We observed that some carbon rich properties such as Richardson Acquisition, Parker Ranch, Willow Creek Acquisition, and Mindengo Hill Acquisitions have a relatively low number of acres converted under the HBU scenario. In contrast, consistent to our previous finding (Figure 4), we noted that properties such as Montesol

Ranch and Usal Forest Shady Dell Acquisition are characterized by both a high carbon density per acre, and a high potential to be developed in the absence of conservation measures.

Figure 6. Top 10 properties in terms of total carbon per acre (grey) and associated acres converted (red) under the HBU scenario. 1. Parker Ranch; 2. Willow Creek Ranch; 3. Cemex Redwoods; 4. Richardson Acquisition; 5. Usal Forest Shady Dell Acquisition; 6. Big River and Big Salmon Creek; 7. Mindego Hill Aquisition; 8. Jenner Headlands; 9. Preservation Ranch; 10. Montesol Ranch.



Results of sensitivity analysis

In the case that the land was developed 50% more for each property than the acreage stipulated in the appraisal report, we found that the total avoided C emissions amount to $130*10^3$ Mg, signaling that approximately 3.18% of total carbon stored across all 57 SCC acquisitions would have been lost. This translates into 75,090 more Mg of aboveground C released into the atmosphere compared to the initial estimate. In terms of avoided land conversions, our results indicated that 20,795 acres or 8.7% of the total land acquired by the SCC would have been converted under this scenario. In the case that the land was developed 50% less than the acreage stipulated under the HBU, then the total avoided C emissions would have been $24*10^3$ Mg, or approximately 0.6% of the total aboveground C stored. While looking at amount of land conserved, we found that 2.9% of the total land across the 57 properties would have been lost under this counterfactual scenario.

The results of our sensitivity analysis show that even in the scenario where we are underestimating the amount of acreage developed in the landscape, the amount of carbon that actually was prevented from being converted is quite small (under 5% of stored aboveground carbon). This result also highlights that aboveground C loss is more sensitive than land acreage converted with respect to land use changes. Specifically, when we increased the amount of land converted by 50% we found that this translated into 2.35 times more aboveground C released into the atmosphere as a result of the land cover change, while the acres of land converted roughly doubled. This is because as the amount of development increases, grasslands used for development are all converted, leading to further conversions onto more carbon-dense vegetation types.

To further assess the choice of a 50 km buffer, we designed a 25 km buffer as an alternative and observed the following. We found that the vegetation conversion trends remain largely the same. Specifically, the vegetation types that had the largest percent of conversion from 2001–2010 within the 50 km buffer were mostly the same as those found in the smaller buffer area, with few exceptions (Table 4).

Table 4. Top vegetation classes converted between 2001 and 2010.

Top 5 vegetation classes converted between 2001–2010 to development within the	
50 km buffer	25 km buffer
1. Grassland (herb cover ≥ 40% and ≤ 100%)	1. Grassland (herb cover ≥ 40% and ≤ 100%)
2. Mesic Chaparral, (shrub height > 3m)	2. Grassland (herb cover ≥ 20% and < 40%)
3.Shrubland (shrub height > 3m)	3.Shrubland (shrub height > 3m)
4. Grassland (herb cover ≥ 20% and < 40%)	4. Mesic Chaparral, (shrub height > 3m)
5. Northern and Central Dry-mesic Chaparral (shrub height > 3m)	5. Northern and Central Dry-mesic Chaparral (shrub height > 3m).

Discussion

Land cover changes that expand impervious surfaces and convert natural habitats to other uses can substantially affect ecosystem's carbon storage capacity (Houghton et al., 2012; Houghton & Nassikas, 2017). Since coastal landscapes such as coast redwood forests are carbon-rich ecosystems, protecting these lands may also conserve significant amounts of aboveground C, and thus, contribute to California's emission reduction goals. Throughout the state, conservation measures (such as zoning regulations, conservation purchases, conservation easements, etc.) have been designed to protect the health and function of coastal ecosystems, and to preserve the scenic, and recreational value of these lands (Endicott, 1993; Newburn, Reed, Berck, & Merenlender, 2005; Yonavjak & Gartner, 2011; Wilson et al., 2015; Owley & Rissman, 2016). However, a common challenge to policy makers, and resource managers is understanding the effectiveness of such policies. To address this gap in knowledge, we empirically quantified the avoided land use conversions and the associated avoided C emissions that resulted from land acquisitions funded by the SCC.

Our findings suggest that the top vegetation classes that experienced the most conversion were: grasslands (of various percent cover), mesic chaparral, northern and central dry mesic chaparral, montane woodland and chaparral, and coastal scrub. These results are fairly consistent with previous findings. For example, Syphard, Brennan, and Keeley (2018) studied habitat conversion in Southern California from the beginning of the century to present, and concluded that urban growth is the primary contributor to the loss and fragmentation of chaparral landscapes. Housing development was found to also indirectly contribute to chaparral conversion by facilitating the expansion of weedy non-native annual grasslands. While analyzing the coastal scrub vegetation type (considered one of the most threatened vegetation types in North America (Cox, Preston, Johnson, Minnich, & Allen, 2014; Noss, Laroei, & Scott, 1995), Cox et al. (2014) found that coastal sage scrub vegetation experienced significant loss throughout the state, being converted either to agriculture or to exotic annual grassland.

The documented land conversion trends found throughout this study suggested that development preferentially took place on low carbon dense vegetation such as grasslands, as opposed to high carbon rich vegetation such as forests. This may be due to factors such as the costs of land conversion associated with different vegetation types, and the suitability of the land for agricultural conversion (planting vineyards). In some cases, grasslands and mesic chaparral ecosystems are easier to convert than other vegetation types such as conifer forests. In addition to this, we hypothesize that development preferentially occurs on grasslands since some vegetation types such as oak woodlands benefit from a higher level of protection. For instance, the Oak Woodlands Conservation Act of 2001, recognizes the ecological value and multiple benefits stemmed from oak dominated ecosystems, and highlights the importance of protecting and preserving the health of these natural habitats (State of California Wildlife Conservation Board, 2017).

In terms of avoided carbon emissions, high levels of avoided carbon loss were calculated for properties that had more extensive development plans, or where development would have occurred on carbon dense vegetation (i.e. coast redwood forests). Our results showed that the vegetation type (and thus carbon density) on the property plays a critical role in determining the amount of aboveground C stored. Consequently, the low avoided C loss relative to avoided conversions (5.6% of all potential acres) is likely driven by two factors.

First, the highest C dense ecosystems (i.e. coast redwood forests) in the SCC's portfolio are located along the North Coast, – in rugged areas, where there is less demand for residential development, and relatively low amounts of agricultural production. The greatest fluxes of carbon often result from conversion of forests to open lands, but demand for conversion of high-carbon ecosystems is relatively low in that part of the state, due to the remoteness of the area, far away from major urban centers (Houghton & Goodale, 2004). SCC acquisitions such as Jenner Headlands, Red Hill Ranch, and Montgomery Woods are examples of conserved properties on which little development would have taken place under the HBU scenario. These properties are also characterized by carbon-rich forested ecosystems located in remote coastal areas.

Second, the relatively low percentage of avoided C emissions can be attributed to our observation that development preferentially occurs on lower C density vegetation types, especially grasslands and shrublands. For the properties we analyzed, over 60% of all conversions occurred on grasslands, while another 17% took place on chaparral. These two factors combined suggest that the potential for SCC acquisitions to avoid significant amounts of C emissions is relatively modest.

Within this study we estimate the type of vegetation converted, however, we do not predict exactly where this conversion will happen on the land. There are a number of different factors that may influence the spatial arrangement of potential development in the absence of conservation measures. The topography and steepness of the terrain would be a critical determinant for the placement of housing units on the counterfactual landscape. In addition to this, a parcel's access to roads, and utilities (such as water and electricity), may also determine the geographic location of residential communities (Forsburg, 2012). The remoteness of the property also can influence its highest and best use (Forsburg, 2012). For instance, SCC acquisitions located closer to major urban centers are more likely to have some type of development as the urban area expands on adjacent lands. These factors are accounted for in the appraisal report when determining the amount of development possible on the land under the HBU scenario.

When analyzing the total carbon emissions resulting from land conversion to other uses, it is important to recognize that over time, some of the aboveground C lost because of urban or agricultural development may be recovered by tree planting in residential areas, and crop growth on agricultural lands, as yards and vineyards mature. For instance, mature vineyards can contain over 4 Mg C/ha (Carlisle, Smart, Williams, & Summers, 2010). Urban forests in coastal California have C densities averaging more than 15 Mg C/ha, with values as high as 35 Mg C/ha in Marin County (Bjorkman et al., 2015). These values are greater than average aboveground C values for grasslands and some shrublands. Further research into carbon sequestration of urban ecosystems would permit for more accurate assessment of aboveground C trends in the face of land conversion.

Moreover, while purchasing lands for conservation purposes prevents conversion in one area, reducing the environmental pressure in a particular place, it does not decrease the overall demand for housing or agricultural lands. This displacement of land use (leakage) may cause land change in other areas (Lambin & Meyfroidt, 2011). Therefore, this demand for development may simply manifest somewhere else on the landscape (spatial spillovers), causing conversions in other places (Andam et al., 2008; Aukland, Costa, & Brown, 2003; Gan & McCarl, 2007; Lambin & Meyfroidt, 2011). However, by decreasing the supply of land for housing and agriculture, conservation acquisitions may increase local land prices, reducing demand and potential conversions, while also affecting C emissions resulting from vehicle use (Armsworth, Daily, Kareica, & Sanchirico, 2006).

Yet another potential effect of land conservation is that designating an area as protected could be attracting more development in lands adjacent to it. In some cases, if a conservation area is established, some people will be more eager to live close to the newly designated green space (Wu & Plantinga, 2003). This is a dynamic that we do not address throughout the study. Furthermore, generally speaking, there have been cases in which conservation easements allow for a certain density of development to take place within the spatial boundaries of a specific property on which the easement was placed (Qwley & Risssman, 2016). In the case of the lands acquired by the SCC, the amount of permissible developable acres was extremely limited, and in fact zero for most parcels. Therefore, we assumed that once a property was purchased by the agency, no significant development would have occurred on the land.

Taking into account the competing forces that stem from the dynamic feedbacks of land cover changes, it unclear how much, if any, of the avoided conversions took place in other locations. Likewise, if some conversions did happen, we do not know if these conversions happened in places with higher or lower carbon density. In addition to this, sudden shifts in government and/or zoning regulations, and various market pressures could influence the amount of land conserved, and therefore, change the calculation of the impact of land acquisitions. Given these uncertainties, it is important to interpret our results as only the direct impacts of land acquisition.

Throughout the study, we do not incorporate the belowground C pool since it is difficult to obtain good estimates of belowground C (Marziliano et al., 2015), and it was beyond the scope of our analysis. If belowground C estimates would have been included, then the amount of C lost due to land conversion would have been larger than the calculated amount, given that the belowground woody biomass (coarse roots) represent a significant underground C pool (Berhongaray., Verlinden, Broeckx, Janssens, & Ceulemans, 2017; Chen et al., 2018). Finally, it is worth mentioning that the lands purchased by the SCC are not randomly selected, therefore, the set of properties analyzed does not represent a random sample of parcels. However, they are located across the northern, central, and southern coastal portions of the state, and therefore, due to their spatial location, variation in size, vegetation cover, and landscape characteristics, they encompass a group of land that is broadly representative of California’s coastal ecosystems.

Conclusion

Given the importance of terrestrial ecosystems for climate change mitigation, it is important to consider the role of open space conservation in above ground C sequestration. Since terrestrial ecosystems play a critical role in the global carbon cycle, improved land management practices can help reduce C emissions. Conserving coastal lands accomplishes a range of conservation values and purposes including: preserving coastal public access, maintaining the recreational and scenic properties of the landscape, conserving valuable coastal natural resources, and preserving stored aboveground C. Further exploring the association between land conversion and aboveground C is a crucial step for improving land management strategies aimed to enhance the carbon storage capacity of natural lands, and can help inform conservation and planning decisions. Additional research is needed to examine and document the interactions between conservation and management actions, land cover changes, and associated C emissions at local and regional scales. Future efforts should be focused on exploring the role of land management in maintaining the carbon sequestration potential of coastal areas.

In this study, we proposed a new framework that can be used to quantify the potential avoided land cover changes resulting from conservation purchases. We believe that incorporating expert-driven appraiser information provides new, valuable insight to counterfactual scenarios. Additionally, integrating neighboring land conversion trends helps inform which vegetation types are primarily transformed to development, along with their associated conversion rates.

Empirically, our results suggest that the avoided development is not associated with a large amount of avoided emissions within California's coastal region. However, adequate management of carbon rich ecosystems can potentially enhance the carbon sequestration potential of coastal lands, and can substantially limit emissions. Forest management practices, for example, can influence the dominant fuel type across large areas, and can impact the C storage capacity of forested ecosystems (Bellassen & Luyssaert, 2014; Noorments et al., 2015). Management techniques such as: maintaining continuous forest cover, supporting litter production and natural ecological conditions, and adopting longer rotation times, can help increase the C sequestration potential (Gelman et al., 2013). Additionally, actions that focus on managing fuel loading to reduce fire risk can help prevent significant C loss resulted from large, high-intensity, catastrophic fires (Stephens & Ruth, 2005). All in all, even though our results suggest that conservation purchases have contributed a relatively modest amount of avoided C emissions, effective management of natural ecosystems can potentially make an important contribution to net removal of $CO_2$from the atmosphere during this century.

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